TITLE: Multisensory perception: Magnetic disruption of attention in human parietal lobe

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40-word summary: Paying attention to sounds and touches at the same time is demanding. New research shows how the parietal lobe of the human brain mediates multisensory perception of stimulus frequency and intensity.

TEXT: Eyes staring at this Dispatch article taking shape on the screen; fingers tapping along with the beat of the engrossing tune played over the headphones. Bzz!... Bzzz!... Bzzzz!... BZZZZZ! Our attention is drawn from the screen and from the music, to our fingers. Something broke our concentration. It was lower frequency, cruder, and louder than the music, but what was it? A mosquito? A meteorite? No, a vibrating phone! Probably an impatient editor calling about the article. Ignore. Re-focus and keep writing. In this issue, Convento and colleagues show how the human brain's parietal lobe may mediate just these sorts of switches of attention, from hearing to touch, when we strive to perceive the differences in frequencies and intensities of touches and sounds [1].

Our world is multisensory, experienced though (at least) five main senses: vision, taste, smell, hearing, and touch. Vision, taste, and smell have quite separate chemical systems for converting light, foods, and odours into electrical impulses in our nerves. Both hearing and touch, however, convert mechanical inputs into electrical impulses through stretch, pressure, and vibration of specialised cells in our skin and ears. The similarity between audition and touch can create multisensory illusions [2], or interfere with behaviour [3]. Sometimes our hands and our ears may tell us the same things, but often they give us different information. So, how does the brain switch attention from the music over our headphones to the vibrations under our fingers and back again?

Multisensory, or crossmodal, attention and perception has been of great interest to psychologists and neuroscientists for many years [4], however, important questions remain unanswered. Can all our senses interact with each other equally? Are there any rules or principles for merging information across the senses [5-7]? Is there a single brain system for switching our focus of attention between sensory streams, or is each potential sensory interaction governed by different brain systems? [8]. The new study by Convento and colleagues [1] addressed some of these attentional issues using magnetic brain stimulation.

Placing a powerful electromagnet close to the brain, and turning it on and off very quickly can produce an electrical current in the muscle and brain tissue underneath. This electrical current can, if positioned and timed appropriately, interfere with whatever processing the brain was doing at the time. Position the magnet over the brain's movement areas and your muscles may twitch [9]. Position it over the visual areas and you might see a flashing light [10]. Position it over the touch areas, as Convento and colleagues set out to do, and you might fail to perceive touches on your fingers.

The healthy participants in this new study were asked to do several different things, sometimes separately, and sometimes together. Sometimes they had to compare the frequencies or intensities of two vibrations on their fingers. Other times they were asked to compare the frequencies or intensities of sounds presented over earphones. In a final condition, participants were asked to compare the frequencies or intensities of a sound in their ears, with those of a vibration on their fingers. Comparing a sound and a touch arising from different locations in space is difficult enough [11], but Convento and colleagues made this task even more difficult for their volunteers by applying electromagnetic stimulation over the brain areas thought to be involved in these crossmodal judgements.

As the researchers expected, magnetic stimulation made the volunteers much worse at almost all of the tasks they were asked to do [FIGURE 1, downwards arrows]. Surprisingly, participants were worse at perceiving both touches and sounds, even when the brain area stimulated was not one traditionally thought to be involved in processing this sensory information. Magnetic stimulation of the scalp is not always painful, but it can be quite uncomfortable and distracting, and this discomfort and distraction vary significantly and systematically over the scalp (http://tms-smart.info [12]). It is critical, therefore, to include control conditions in brain stimulation studies that can account for the side-effects of the stimulation itself. In half of the sessions of Convento and colleagues' study, as a control, the researchers placed the magnet over the occipital region of the scalp, overlying the brain areas responsible for vision, not thought to be directly involved in touch or hearing. This allowed them to distinguish between the generic effects of scalp stimulation on participants' overall task performance, from the specific effects of stimulating exactly that part of the brain underneath the magnet.

Comparisons between the effects of stimulation over these two brain areas ('S1' and 'Control') revealed some surprising findings. While magnetic stimulation over the touch areas ('S1') interfered strongly with both tactile frequency and intensity perception tasks, stimulation over the control brain area also produced strong effects on both of these tasks (Figure 1, † symbol). Similarly, while stimulation over the touch area interfered strongly with both touch and hearing, stimulation over the control area interfered, just as much, with both sensory systems (Figure 1, ‡ symbol). There were two clear exceptions to these more general effects of stimulation on sensory processing. First, when the volunteers had to divide their attention between touch and hearing, stimulation over the control area had a much smaller effect on auditory frequency perception than stimulation over the touch area (Figure 1, * symbol). Second, and the largest effect overall, participants were most disrupted by brain stimulation when they had to compare touch and sound intensities directly, although this interference was not specific to the brain areas stimulated.

These results are surprising. Why was auditory perception strongly affected by stimulation over the brain areas for touch? Why was there little touch-specific interference when stimulating over the brain areas for touch as compared to over the control area? Solutions to these problems may come from a number of directions. First, perhaps the magnetic stimulation was not sufficiently targeted on the brain area responsible only for tactile perception on the fingers? Future studies, with brain stimulation customised and targeted for each individual, with both structural and, ideally, functional brain scans [13] are required to answer this question. Second, perhaps magnetic stimulation of the brain is not able to interfere with more basic aspects of sensory processing, but instead is most effective only at later, attentional, or comparative stages of processing, either within touch [13], or between touch and other senses [1]. Finally, perhaps the primary sensory areas are not dedicated to processing the relatively low-level information arising from a single sense at all, but operate across the senses, in a truly multisensory or crossmodal way [14].

While most sensory systems have now been studied using magnetic brain stimulation, there is still much work to be done in understanding how these systems process basic information, generate our perceptual experience, and contribute to attention and cognition. One critical next step is to evaluate the precise contributions of different parts of sensory cortex to our perception of touches and sounds. The brain regions responsible for processing touch and the other bodily senses comprise at least six different brain areas – four in the 'primary' zone [15], and at least two 'secondary' brain areas. How can magnetic brain stimulation be used to tease apart the contribution of these different areas to our senses of touch and hearing? The primary sensory areas are organised in 'maps' [16], with body parts and sound frequencies represented systematically across the brain surface, both within and between hemispheres [17]. Which specific parts of these maps mediate the sharing of information and shifting of attention between touch and hearing? Why might the fingers, in particular, mediate the transfer of auditory information? Could these functions be served, instead, by a part of the tactile brain that does not specifically or only represent the fingers?

Magnetic brain stimulation will continue to be a powerful tool for crafting answers to these questions in the years to come. Navigated brain stimulation will help us to understand how multisensory attention is captured, shifted, and controlled [18]. These advances in knowledge may, for example, help the design of smartphone technology to optimise crossmodal attention, minimise crossmodal distraction, and make us more productive.

REFERENCES

1. Convento, S., Rahman, S., and Yau, J.M. (2018). Selective attention gates the interactive crossmodal coupling between perceptual systems. Curr. Biol. *This issue*.
2. Jousmäki, V., and Hari, R. (1998). Parchment-skin illusion: Sound-biased touch. Curr. Biol. *8*, R190.
3. Yau, J.M., Olenczak, J.B., Dammann, J.F. III., and Bensmaïa, S.J. (2009). Temporal frequency channels are linked across audition and touch. Curr. Biol. 19, 561–566.
4. Spence, C., and Driver, J. (1996). Audiovisual links in endogenous covert spatial attention. J. Exp. Psychol. Hum. Percept. Perform. *22*, 1005–1030.

5. Holmes, N.P., and Spence, C. (2005). Multisensory integration: Space, time, and superadditivity. Curr. Biol. *15*, R762–R764.

6. Holmes, N.P. (2009). The principle of inverse effectiveness in multisensory integration: Some statistical considerations. Brain Topog. *21*, 168–176.

7. Parise, C.V., and Ernst, M.O. (2016). Correlation detection as a general mechanism for multisensory integration. Nature Communications, *7*, 11543.

8. Spence, C. (2002). Multisensory attention and tactile information-processing. Behav. Brain Res. 135, 57–64.

9. Hallett, M. (2007). Transcranial magnetic stimulation: A primer. Neuron *55*, 187–199.

10. Cowey, A., and Walsh, V.Z. (2000). Magnetically induced phosphenes in sighted, blind and blindsighted observers. NeuroReport *11*, 3269–3273.

11. Spence, C., and Driver, J. (1997). On measuring selective attention to an expected sensory modality. Percept. Psychophys. *59*, 389-403.

12. Meteyard, L., and Holmes, N.P. (under review). TMS SMART – scalp mapping of annoyance ratings and twitches caused by transcranial magnetic stimulation. J. Neurosci. Methods.

13. Tamè, L., and Holmes, N.P. (2016). Involvement of human primary somatosensory cortex in vibrotactile detection depends on task demand. NeuroImage 138, 184–196.

14. Ghazanfar, A.A., and Schroeder, C.E. (2006). Is neocortex essentially multisensory? Trends Cogn. Sci. *10*, 278–285.

15. Kaas, J.H. (1983). What, if anything, is SI? Organization of first somatosensory area of cortex. Physiol. Rev. *63*, 206–231.

16. Sood, M.R., and Sereno, M.I. (2016). Areas activated during naturalistic reading comprehension overlap topological visual, auditory, and somatotomotor maps. Hum. Brain Mapp. *37*, 2784-2810.

17. Tamè, L., Braun, C., Holmes, N.P., Farnè, A., and Pavani, F. (2016). Bilateral

representations of touch in the primary somatosensory cortex. Cogn. Neuropsychol. 33, 48–66.

18. Bolognini, N., and Maravita, A. (2011). Uncovering multisensory processing through non-invasive brain stimulation. Front. Psychol. *2*, 46.

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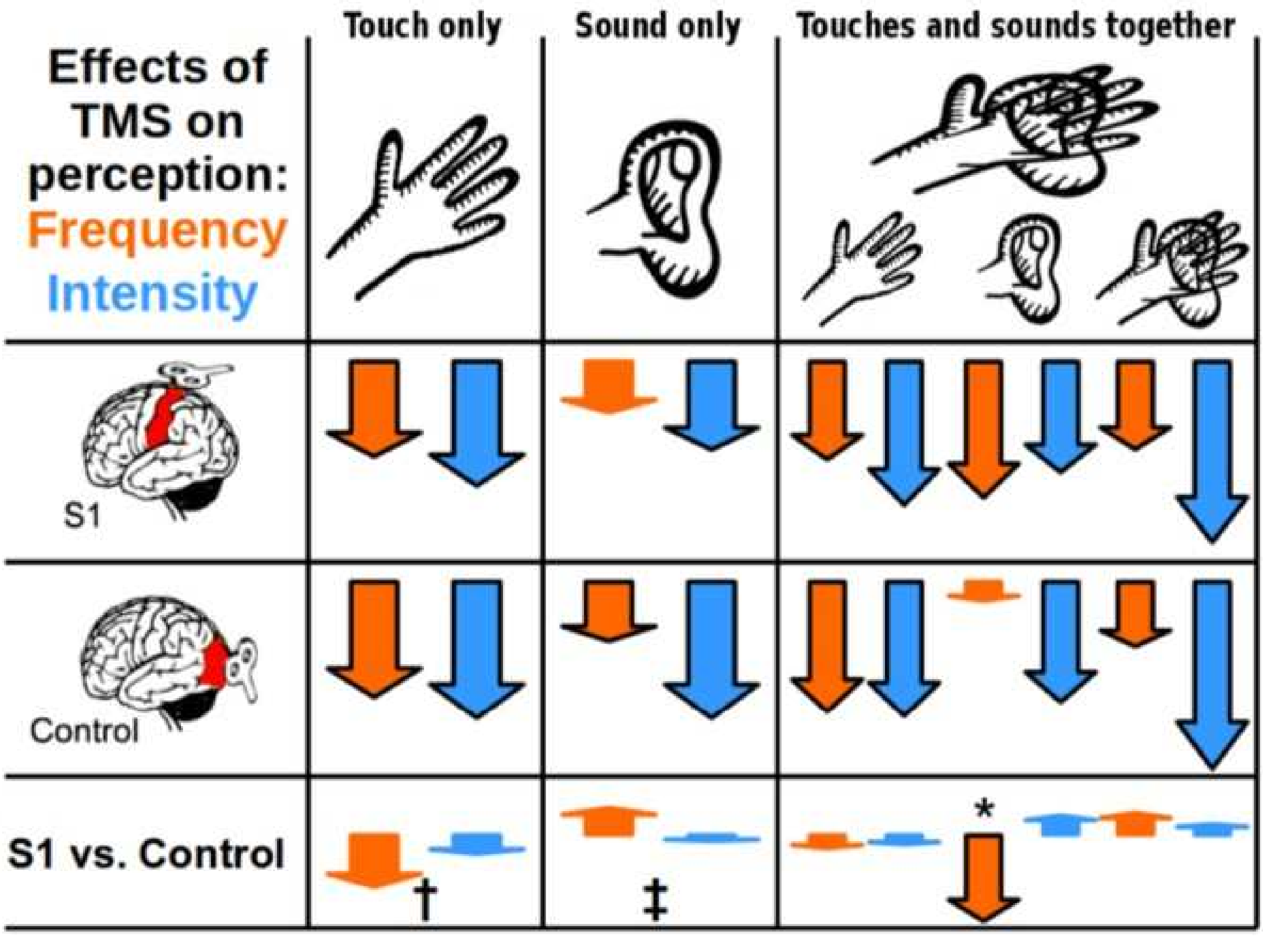

Figure 1. Transcranial magnetic stimulation (TMS) impairs tactile and auditory perception

Hand images show tactile, ear images auditory, and mixed images show mixed tactile-auditory tasks. Arrows show the effect sizes (Cohen's d, compared to baseline without TMS) for brain stimulation over the touch area (S1), the visual area (Control), and the differences between S1 and Control areas (bottom row). Black outlined arrows: $p \leq .05$, uncorrected. Orange: frequency. Blue: intensity perception. No significant interaction between the presence and location of TMS for tactile(†) or auditory perception(‡) alone, but a significant interaction for auditory frequency perception in the mixed blocks(*). (Reanalysis of Convento and colleagues' data, available at https://osf.io/cwzsp/).